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## THERMOCOUPLES FOR FOREST FIRE RESEARCH

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### ABSTRACT

Thermocouples have proved valuable in research conducted by the Fire Physics Project at the Northern Forest Fire Laboratory because they can measure several important fire variables besides flame and convection column temperatures. These include rate of spread and flame residence time. Describes a simple, rapid method of fabrication and reports useful and diverse applications of thermocouples in laboratory and field use.

During the past  $2\frac{1}{2}$  years, the Northern Forest Fire Laboratory has gained considerable experience in using thermocouples for measuring temperatures and marking such events as distinct rise or decrease in temperature in free-burning fires. This report summarizes our results to date in order to help others who may need to make similar measurements.<sup>1</sup> It also gives directions for fabricating similar devices.

### TECHNOLOGY

Thermocouples are very convenient and useful for measuring temperature in many different applications. They are small, light, relatively inexpensive (except platinum thermocouples), can be mounted at a considerable distance from the indicating instrument, and can be used in places inaccessible to ordinary thermometers.

A thermocouple is simply a junction of two dissimilar metals; at this junction there is a difference in electrical potential. If two junctions are formed by joining both ends of two dissimilar conductors, and if all parts of the circuit are at the same temperature, no current flows as the e.m.f.'s (electromotive forces) around the circuit are equal and are in opposite directions. If one junction is heated, its e.m.f. increases and the two junctions no longer balance. Current

<sup>1</sup> Anderson, Hal E. Mechanisms of fire spread, research progress report no. 1. U.S. Forest Serv. Intermountain Forest and Range Expt. Sta. Res. Paper INT-8, 20 pp., illus. 1964.

flow may be measured, or the circuit may be opened at one place and attached to a potentiometer to measure the net e.m.f. acting around the circuit. This thermoelectric effect may be used to determine the temperature of one junction if the temperature of the other junction (a reference junction maintained at a constant temperature) is known.

The reference junction is a means of connecting a thermocouple to the copper leads of a measuring or indicating system without incurring the errors normally associated with thermal electromotive forces produced at unintended secondary junctions. In installations where power and space are not critical, the problem is solved by maintaining the junction of the thermocouple and copper leads (cold junction) at a constant temperature (with a constant-temperature bath) so that the error attributable to thermal electromotive force is constant and can be calibrated out of the measuring system. This requires time for temperature stabilization before measurements are made.

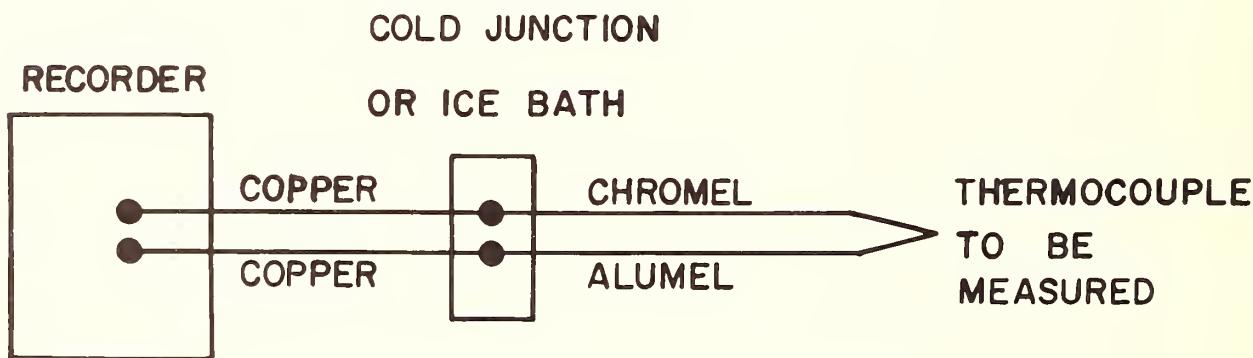


Figure 1.--Basic system of a thermocouple, cold junction, and recorder.

#### TEMPERATURE MEASUREMENT

In the application of thermocouples for temperature recording, the temperature range to be measured must be roughly estimated. The type and gage size is then selected; smaller gages give faster response, but their service life is shorter. The three most commonly used types of thermocouples and their temperature ranges<sup>2</sup> are:

Chromel-alumel	-300 to 2,200° F., maximum 2,450° F.
Iron-constantan	-320 to 1,400° F., maximum 1,800° F.
Copper-constantan	-312 to 650° F., maximum 1,100° F.

Chromel and alumel (nickel base alloys that have excellent tensile properties) are more widely used than other materials because they have a higher temperature range. We have obtained thermocouple material as small as 0.001 inch. When fabricated in the workshop, these are best joined by spot welding, or they can be bought commercially already made up as thermocouples. Larger sizes can be gas-welded by using an oxyacetylene flame and a flux, or by arc welding. Arc welding provides a cleaner bead, a positive fusion, and no oxidation.

<sup>2</sup>Shenker, Henry, John I. Louritzen, Jr., Robert J. Corruccini, and S. T. Lonberger. Reference tables for thermocouples. National Bureau of Standards Cir. 561, 84 pp. 1955.

Thermocouples measure the temperature differential between two junctions of dissimilar metals and thus provide a relative measure. Other types of temperature measuring devices are the thermistor and the resistance thermometer, both of which measure absolute temperature.<sup>3</sup> The fine wire resistance thermometer is capable of almost the same response as a thermocouple, but its sensing element involves a definite length of wire rather than a point and hence gives the average temperature of the wire. Some additional equipment--including a current source and bridge elements--is needed.<sup>4</sup>

#### FABRICATION

A simple autogenous welder for rapid fabrication of butt-welded thermocouples can be made from a piece of 2-inch iron pipe 2 inches long butt-welded to a steel plate insulated from electrical ground. Power for welding is provided by a 0-100-volt variable voltage a.c. transformer to compensate for differences in gage of thermocouple wire. One output lead from the transformer is attached to the steel plate; the other lead is attached to the bare ends of the thermocouple. The end to be fused is cleaned of all insulation for about one-fourth inch, and the wires are then twisted together no more than one turn for good sensitivity. Clean mercury is poured into the well to approximately 3/8-inch deep, and an oil having a high flash point, such as transformer oil, is poured on top of the mercury. The oil prevents flashing and the release of mercury vapor, which is toxic. The voltage is set at 20 volts. The twisted end is dipped into the well through the oil to the mercury, where the twisted end will arc because of the continuity of current flow. If fusion does not occur at 20 volts, the voltage is increased gradually in successive trials until fusion is achieved.

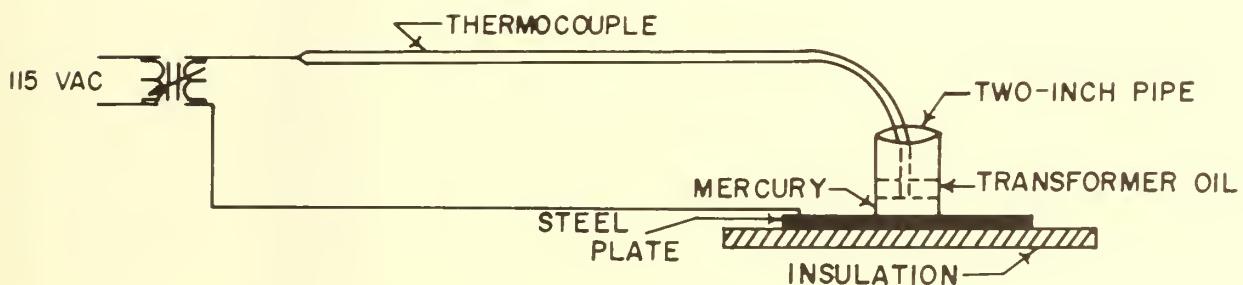


Figure 2.--Thermocouple welder.

<sup>3</sup> Fenwal Electronics. Thermistors--how they compare with thermocouples, resistance thermometers. Capsule Thermistor Course #7, Electronic Design 12(5): 32. 1964.

<sup>4</sup>Hunt, Maynard H. Design and use of fine wire thermocouples for research. U.S. Naval Ordnance Test Station, China Lake, California, 35 pp., illus. September 1959, unclassified.

Figure 3.--Thermocouple  
encased in  $\frac{1}{4}$ -inch  
copper tubing.

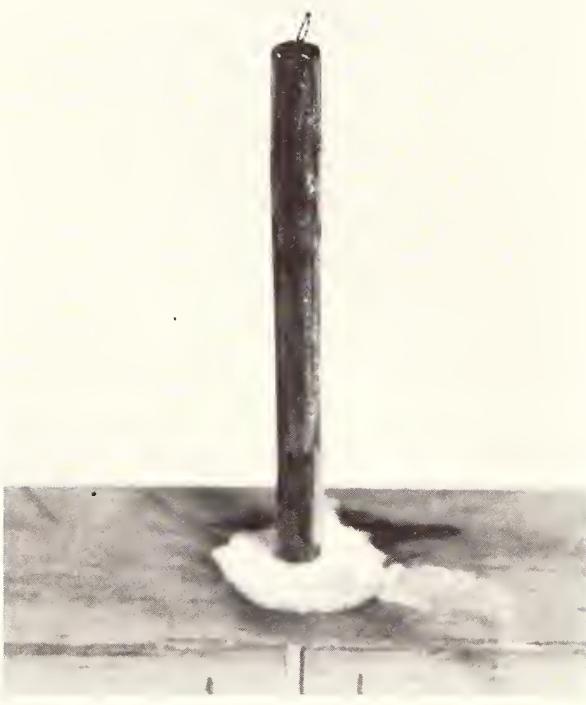


Figure 4.--The same  
thermocouple pro-  
tected with 5/8-inch  
copper tubing for  
insertion into fuel  
bed.



## APPLICATIONS

Thermocouples (fig. 3) placed just beneath the surface of a fuel bed and evenly spaced along its centerline have provided considerable information about fire characteristics. The stems of the thermocouples were incased in porcelain insulators inside  $\frac{1}{4}$ -inch copper tubing and sealed with Saureisen sealing cement.<sup>5</sup> In use, the thermocouple junction should protrude one-eighth inch above the copper tubing and should be insulated to reduce the error from conduction. The thermocouple is protected before being inserted into the fuel bed by a cap made of 5/8-inch copper tubing closed at one end (fig. 4). We attached thermocouples to two boards 1 inch by 2 inches by 4 feet for ease of handling 12 thermocouples used in fuel bed tests.

The fuel beds used in the laboratory are 8 feet long by 18 inches wide. Starting 3 inches from one end, we drilled holes 9 inches apart in the base for thermocouple insertion. The thermocouples protrude to within one-fourth inch of the upper surface of the fuel. As the fire passes each thermocouple, the temperature profile is traced on an oscillograph. From the thermocouple trace, in addition to the temperature profile, both the rate of spread and residence time of the fire can be obtained. The types of thermocouples used in laboratory tests in the fuel bed are chromel-alumel 30-gage twisted and butt-welded. For measuring flame and lower convection column temperatures, we have used 24-gage butt-welded chromel-alumel thermocouples placed 3 inches apart and suspended 1 foot above the fuel bed. Butt-welded iron-constantan thermocouples 3 inches apart have been used at the 3-foot level. Five thermocouples wired in parallel and located in the exhaust stack were used for measuring convection temperatures.

## FIELD USE

In a field test at Priest River Experimental Forest in northern Idaho, fuel beds 60 feet long by 6 feet wide with varying depths were constructed from Douglas-fir and lodgepole pine slash in which the limb sizes were varied. Measurements recorded during the burning included the rate of fire spread, flame depth, vertical temperatures within and above the flame, flame base temperature profile, and residence time. The temperature instrumentation consisted of 48 thermocouples made of 24-gage chromel-alumel asbestos and fiberglass-covered wire. The leads for each 12 thermocouples were brought to an ice bath, then to a box of 24 switches that could switch to any station of 12 thermocouples. The leads were then brought to two light-beam oscillographic recorders. This arrangement permitted all four stations of a fuel bed to be monitored with two recorders by switching as the flame front progressed from station to station. The instrumentation stations were designed to be as portable as possible. The assembly was fabricated in the shape of an "F" from  $\frac{3}{4}$ -inch and 1-inch iron pipe (figs. 5 and 6).

A tee at  $1\frac{1}{2}$  feet supported an arm 6 feet long to which were attached six thermocouples 9 inches apart. These were suspended 6 inches above the fuel. The upper and lower arms of the "F" assembly,  $9\frac{1}{2}$  feet apart, were interconnected with piano wire. Six thermocouples were attached vertically to the wire at known heights. One thermocouple was used with a Kiel probe for measuring convection column temperature and pressure. The pressure signal was measured by a differential pressure transducer and displayed upon a single-point strip chart recorder.

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<sup>5</sup> Saureisen No. 33 is a ceramic adhesive, fireproof, resists acids, and has good electrical insulating properties.



Figure 5.--Thermocouple support system positioned over a slash fuel bed prior to the fire. Note white tie-downs for thermocouples on horizontal and vertical sections.

Figure 6.--Thermocouple assembly engulfed in flame. This type of assembly presents minimum obstruction to the fire.

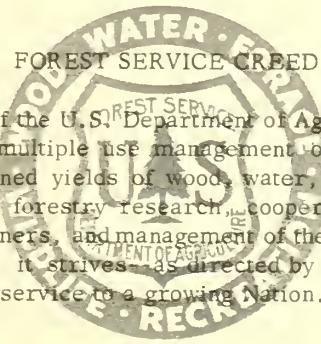


After use in 18 fires the thermocouples were damaged and charred but were still functioning well. One basic objective of the field experiments was to test measurement techniques and the adaptability of laboratory instrumentation to field operations. Use of thermocouples in the field is certainly feasible. Thermocouples must be handled carefully after fabrication. Also, special care must be taken with the thermos bottles used for the reference junction ice baths. Thermos bottle cold junctions are not well suited to field testing because of the difficulty of obtaining ice in remote areas and the possibility of breaking the bottles. A possible alternative would be to place the junctions underground and then monitor the junction temperature with a separate sensor. Another method would be to use either a self-powered or an externally powered thermocouple reference junction compensator. The first, of course, requires no outside power source and therefore is ideal for field use; but the externally powered compensator would have to have either an a.c. or d.c. power source. Compensators are manufactured to match the thermocouple material used and also for specified reference temperature. They cost more, but the added convenience could offset the cost.

## SUMMARY

Thermocouples have proved to be the most useful device for measuring temperature phenomena in fire research because many materials and wire sizes are available. Thermocouples for studies at the Northern Forest Fire Laboratory have been fabricated with the use of a mercury pool arc welder; they have proved reliable and accurate.

Thermocouple systems have been developed to measure flame and air temperatures and to serve as event recorders. They have facilitated measurement of rate of spread, residence time, flame envelope profile, and temperatures within the flame and in the convection column. The potential use of thermocouples can be great, and is dependent mainly on the ingenuity of the user.



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